INDUSTRIAL HYGIENE SECTION

This Industrial Hygiene Section is published to promote sound thought upon and concerning industrial hygiene. To that end it will contain articles, discussions, news items, reports, digests, and other presentations, together with editorial comments. The editorial policy is to encourage frank discussion. On this basis contributions are invited.

Industrial Medicine

Reg. U. S. Pat. Off.

The Editorial Committee will exercise its best judgment in selecting for publication the material which presents most exactly the factors affecting industrial health and developments for control of potentially injurious exposures. The editors may not concur in opinions expressed by the authors but will endeavor to assure authenticity of fact.

The Science, the Law and the Economics of Industrial Health

Volume 3 July, 1942 Section 3

The Shifting Scene

THE main job before us today is to help bring the war to a successful conclusion. Many of our associate members are now on active duty with the Army, the Navy, or the Public Health Service. Some are serving in the medical corps, in the artillery, in the chemical warfare service, and others in the sanitary corps of the Navy. Our treasurer, THEODORE HATCH, will be associated with DR. WILLARD MACHLE at the new laboratories of the Armored Forces. Our first president, WILLIAM P. YANT, has been sent to England on industrial hygiene matters of interest to us and to our allies. The Navy has sent several groups of doctors and engineers to Columbia and to Harvard for special courses in industrial hygiene. This kind of thing shows that we, as a profession, are beginning to attain recognition. No longer are we considered simply an appendage to our industrial medical colleagues who, of course, far outnumber us. As a group they have been our warmest supporters.

As a society we watch with grave misgivings the inroads "procurement" is making among industrial physicians and industrial hygienists. Why should not the industrial hygiene personnel (physician and engineers) of a manufacturer whose entire output now goes to the government be just as essential as that in a government owned and operated plant? At this writing it is not, but we believe it should and hope it will be.

In general the Army, Navy, and Public Health Service are exchanging freely information on available industrial hygiene personnel. They are not raiding the state bureaus but they need men; if a good man from a state bureau applies to these government agencies of his own volition, then they are apt to accept him. There is nothing unfair about this. Unquestionably industry on the other hand has been raided, but it expected raids. We have heard some spicy language from the executives of companies so raided, but it was usually tinged with pride that the government stole "our men when they needed good ones." The victims of such depredations might feel a little better if they realized that the thievery continues after the individual is in the government service—good men are transferred about to bolster up weaker departments.

There have been comparatively few women in industrial medicine and almost none in industrial hygiene. Many of the industrial medical and industrial hygiene jobs in the government services must be filled by men. At present there is no provision for the inclusion of women as commissioned officers in any of these services except as nurses. Industry is not so handicapped. Some plants are now hiring women doctors to take over the care of new women factory workers. Some companies are hiring and training women chemists for the laboratory phases of industrial hygiene, a field in which women should be able to compete successfully with men.

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Women have not gone into sanitary, chemical, mining, mechanical, or electrical engineering, the professions which are apt to lead men into industrial hygiene. There are a few exceptions to this generalization, but not many. If our Association furnishes men to the government their places are apt to be taken by women, providing women can be found with enough engineering or mathematics to fill the bill. It is most improbable that industry can find new men to fill the places of industrial hygienists who leave. It is likely, then, that we, who do not enter the government service, will be asked to help in training women for industrial hygiene work.

—PHILIP DRINKER

Health Hazards in Steel Mills

J. WM. FEHNEL,
Metropolitan Life Insurance Company, New York

IN THE nation's "all-out war" effort, the steel industry, above all others, has been called upon to do its utmost. Mr. Cameron, Director of the National Safety Council, recently stated that a lost-time accident is only a means of sabotage. Likewise, lost man-hours due to illness attributed to industrial environment also work to the interests of the Axis powers and refute the Allied efforts.

The Industrial Health Service of the Metropolitan Life Insurance Company has had the opportunity of studying health hazards in the steel industry for the past 10 years and also the exceptional opportunity of rechecking periodically all the plants of one of the larger steel companies. On the basis of this experience, we have been able to draw some definite conclusions and make the necessary recommendations for the control of the health hazards in this industry.

Various raw materials are purchased in the prepared or purified state, while others are processed in the steel plant. Of course, the principal raw material used is pig iron, and while a few steel plants of small tonnage output operate without blast furnaces, most steel companies make their own pig iron.

The iron ore for the production of the pig iron may be obtained from company-owned mines or it may be contracted for. In the mining of iron ore, the principal health hazard is silicosis. This was evidenced by a survey of iron ore mines made by the Metropolitan Life Industrial Health Service in the upper Michigan district in 1932.

The handling of the iron ore at the blast furnace, however, presents no silicosis hazard, as the ore has been partially refined and concentrated and is free of harmful quantities of silica.

Limestone is used as a flux in the smelting of iron ore and is usually obtained from a nearby quarry operated by the steel company. It is necessary that the limestone be of low silica content, and thus no silica exposure is presented in its production. Also, the quarrying is actually open-pit mining, so exposures to high concentrations of inert dust are comparatively rare. Wagon drill operation and crushing and screening would be the greatest dust-producing operations encountered in the quarrying. Dust may be materially reduced in crushing and screening by operating wet.

Coke is the other raw material extensively used in charging the blast furnace. It is usually produced in by-product coke ovens on the steel company property, often from coal produced in a company mine. The operation of the coal mines presents health hazards due to exposure to silica dust and mine gases, such as methane and carbon monoxide.

The introduction of wet methods and good mine ventilation materially cut down the silicosis hazard. Proper mine inspection and the use of forced ventilation help in the removal of the gas hazard.

The operation of the by-product coke plant presents several specific health hazards. The gas hazard is always present and is so recognized. Employees are warned not to go into confined areas alone and without proper respiratory protective equipment. The use of the safety belt and line, together with a hose mask for entrance into manholes and tanks is mandatory. High concentrations of carbon monoxide have been found in these locations. While excessive quantities of coal and coke dusts are encountered in several departments, these dusts are of a nuisance nature and present no real health hazard.

Various products distilled from the coal and recovered from the gas given off present definite health hazards, but, fortunately, owing to the handling in closed systems, seldom give any trouble.

In the recovery of the ammonia given off with the gas, there is the possibility of burns from the lime used to free the gas from the liquor in the ammonia stills and from the sulphuric acid used to convert the ammonia gas into ammonium sulphate. There is also the possibility of exposure to the inhalation of ammonia gas. In our studies we have not encountered any high concentrations of ammonia in the still houses of by-product coke plants.

In one coke plant, it was noted that small quantities of clay were added to the finished ammonium sulphate to keep it from caking. This clay was found to contain only 2% of free silica. A greater silica hazard usually exists at the mud mills where the mortar used to lute the doors of the coke ovens is made up of clay, loam, and crushed fire brick mixed with water.

THE recovery of the light oils from which benzol, toluene, and xylene are distilled usually presents no health hazards, as these distillations are conducted in closed systems. However, employees may be exposed to high concentrations when cleaning and repairing stills, sludge boxes, and storage tanks. In one survey we found the highest solvent concentrations on the loading wharf. High concentrations were encountered in the still house under abnormal conditions such as a break in the solvent lines and open sludge boxes. However, the solvent leakage on the loading wharf was invariably due to carelessness. Usually only one or two men are employed on the wharf, and if a leaking gasket or valve develops it is not repaired. If leaks are prevented and spillage avoided, there is no solvent hazard in this department.

Employees at the blast furnaces are constantly exposed to varying concentrations of carbon monoxide, sulphur dioxide, and hydrogen sulphide. Carbon monoxide, a by-product in the operation of the blast furnace, is recovered and either used as fuel under boilers or after purifying is used to operate gas engines. The same precautions regarding warning and protection of employees against exposure should be taken as in the by-product coke plant.

Employees on the casting floor are exposed to varying concentrations of sulphur gases, depending largely on the sulphur content of the charge.

It is common practice to do some molding on the

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casting floor. There is some chance of exposure to silica dust from these foundry operations and also in the preparation of luting cement used in the blast furnace.

The operators of the weight cars in the stock house are exposed to some dust of a non-siliceous nature, to dampness and to drafts.

The operation of the pig casting machines does not present any definite health hazards, although the employees are exposed to heat and radiant heat rays, as well as to possible lime burns.

THE operation of the open hearth furnace presents a number of possible health hazards, but strangely little is known of their severity either from studies or reported cases.

The primary hazards are due to the normal operation of the furnace and comprise the possible exposure to high concentrations of carbon monoxide from the gas used to heat the furnaces and to high temperatures and drafts. High concentrations have been found at the checkers below the furnaces and at the change-over valves. The tearing down and relining of furnaces and checkers expose those engaged at this work to concentrations of dust of a high silica content. During forced production this hazard is greatly increased, because the work is started before the furnaces have cooled even slightly. It is common practice to bridge over the red-hot hearth with sheet iron and planking and proceed to tear down the brick roof, using hand labor. As this is strenuous and very hot work, the laborers usually work two to four minutes and rest for a period twice as long. Naturally, this strenuous work, in such a hot atmosphere, greatly increases the rate of respiration and the inhalation of the siliceous dust.

Relining of ladles also presents a silica hazard, often greatly increased by the confined quarters in which it is done. In large plants, a silica hazard usually is presented in the mason department, where large quantities of brick are handled.

EMPLOYEES on the pouring platform and the ladle crane operators are exposed to fumes given off by the hot metal. Substances used to line the molds and those added to the hot metal while pouring may also cause toxic vapors. It is common practice to dip the hot molds, after stripping, into a tank of molten coal-tar pitch. On pouring hot metal into these tarred molds, not only the tar inside the molds is burned and vaporized, but also the pitch adhering to the outside. This latter produces copious fumes of a very acrid nature, containing quantities of anthracene, which are very irritating to the eyes and mucous membranes. In some mills, it is now the practice to spray the inside of the hot stripped mold with pulverized coal tar pitch, thus avoiding the coating of the outside of the mold and practically eliminating much of the obnoxious fumes. In other mills, carbon tetrachloride is added to the mold while pouring. The carbon tetrachloride in contact with the hot metal is broken down into hydrochloric acid, ferric chloride, and possibly some phosgene. Naturally, these fumes are not only obnoxious and very irritating, but so dense that they obscure vision, presenting a serious safety hazard. While high concentrations of these fumes have been determined in the ladle crane cab and on the pouring platform, as well as in front of the furnaces, no damage to employees' health has been recorded, probably due to the intermittent nature of this operation. In some cases, cartridge type respirators have been provided for the crane operators and those on the pouring platform.

Two or three years ago a type of leaded steel was quite extensively produced by the addition of lead shot to the mold at the time of pouring. About 90% of the lead vaporized and boiled off, thus exposing all employees in the open hearth department to varying concentrations of lead fume and dust. A number of cases of lead absorption among these employees was reported.

Atmospheric samples taken on the pouring platform during pouring indicated a concentration of 3.8 milligrams of lead per 10 cubic meters of air and 88.3 milligrams per 10 cubic meters in the crane cab.

Pouring operations using carbon tetrachloride and lead can be controlled by means of applying exhaust to entrap the fumes given off from the top of the mold. Leaded steel is not used extensively at present, as it was found that its metallurgical properties were highly over-rated.

Various other metals are used in producing alloyed steels which are added directly to the charge in the furnace or to the ladle at the time of tapping the furnace. The more common ones are nickel, chromium, ferromanganese, ferrosilicon, titanium, tungsten, and molybdenum. It is common practice to operate a manganese crusher on the charging platform, and concentrations of ferromanganese can be determined when it is in operation.

Air tests taken on the furnace charger and on the pouring platform showed negative quantities of these metals. No fluorides were ever determined. However, small amounts of these metals were detected in rafter dusts collected from these departments.

ONE steel mill surveyed operates a molybdenum reducing plant. The molybdenum ore, in the form of a sulphide, is roasted in the presence of an excess of air which converts it to the oxide. The operation is carried out in a closed system and the plant is free of dust, with the exception of the packaging operation. A slight odor of sulphur dioxide is perceptible at times. The molybdenum oxide is weighed into cans and sealed and is charged into the furnace in this form.

The only health hazard encountered at Bessemer converters was due to silica dust in the department where ladles were relined. The dust was produced by the operation of a silica rock crusher.

In the operation of electric furnaces, copious fumes are given off. In the production of alloyed steels, varying concentrations of the various alloying metals have been found in the atmosphere of these electric furnace departments.

The operation of blooming and rolling mills presents a few health hazards. Carbon monoxide may be present in the vicinity of the heating furnaces. Concentrations ranging from 20 to 100 parts per million are commonly found in the crane cab over the soaking pits. During the rolling of leaded steel, lead is detectable in the atmosphere, and settled dust shows appreciable quantities of this metal.

During the operation of dropping the bottoms of the soaking pits, laborers are exposed to high temperatures and to excessive quantities of iron oxide dust in cleaning out the scale from the ingots.

In the operation of the various types of rolling mills, the hazards are the same as those encountered in the blooming mill. Here again, lead is detectable in the atmosphere if leaded steel is being rolled. In the operation of hot rolls, a lubricant containing a high percentage of animal fat is applied to the rolls at intervals. Considerable acrid smoke containing acrolein is given off.

In the operation of the mills, it is also necessary to do chipping and scarfing. Today scarfing is used more extensively in removing flaws from steel billets before rolling. No health hazard was ever detected in chipping,

with the possible exception of a few employees engaged at chisel grinding in the tool room. Scarfing may produce hazardous fumes in some instances, as, for example, in the scarfing of leaded steel and alloy steel of high chromium and manganese content. There is also an exposure of the eyes to radiant energy from the torch flame.

There is usually a roll shop in connection with each mill. Here machine shop operations predominate, with a possible exposure to lubricating and some cutting oils.

Usually some welding operations are done along with the babbiting of bearings. It is the usual practice to melt the babbit metal in a gas or oil-fired pot that is seldom hooded. The bearings are sweated out of the old lining by heating with a gas flame on the shop floor. Concentrations as high as 15 milligrams of lead per 10 cubic meters of air were found at the sweating out operations, while concentrations as high as 1 to 20 milligrams per 10 cubic meters were obtained at the babbit melting kettle.

A few steel plants do all the babbiting in a shop adjacent to the general machine shop. Some of these plants have adequate exhaust systems to control the fumes.

Pickle and cleaning baths consisting of various acids and alkalies such as sulphuric, hydrochloric, nitric, and hydrofluoric acids, caustic soda, sodium sulphate, and sodium cyanide are used in conjunction with the mills. Some of these solutions are used hot and some are agitated when the steel bars and sheets are immersed in them.

It is common practice to operate the cyanide bath in the vicinity of an acid bath. Accidental introduction of some acid into the cyanide bath could generate dangerous concentrations of hydrocyanic acid gas. Then, too, acid and cyanide solutions can mix when emptying the tanks into the sewer, and the generated gas backs up through sewer outlets into other plant departments.

Employees in pickle departments are exposed to acid fumes and mists, steam, high humidity, and dampness. The burns from hydrofluoric acid are painful and hard to heal. Oxides of nitrogen are found in pickle rooms engaged in cleaning stainless steel.

Increased general ventilation, by means of exhaust fans, is the general means employed to correct conditions in pickle rooms, but local lateral exhausts are now placed along the top edge of bar pickle tanks.

IN THE fabrication departments, a number of health hazards are encountered.

In wire drawing, there is first the pickle room and its ever-present acid fumes. The wire is coated with lime to act as a lubricant on the die blocks. Consequently, a wire drawing department always has lime dust present.

In the making of welded steel tubing, using the quenched arc continuous weld method, no oxides of nitrogen have been detected. In one plant the finished tubes were swabbed with benzol to remove grease and oil. Benzol was used because it was the cheapest solvent present in the plant, a by-product in the production of coke. Gasoline was substituted for the benzol.

In the manufacture of nuts and bolts, screws, nails, and spikes, employees are exposed to high temperatures, lubricating and cutting oils.

The production of tin plate sets up fumes of sal ammoniac and hydrochloric acid. The acid and flux tanks and the tin metal tank are generally hooded, but not always exhausted. In the manufacture of ternplate a serious lead hazard may be set up.

Galvanizing of sheet metal seldom produces any trouble or complaints, although fumes of zinc and sal ammoniac are present in the atmosphere in varying concentrations. In one galvanizing department, employees on the floor were provided with respirators, but no provision was made for the crane operator. In this department there was a possible intake of zinc and lead fumes and dusts of 16 milligrams of zinc and 5 milligrams of lead per 10 cubic meters of air on the operating floor, while in the crane cab there was a similar exposure of 33 milligrams of zinc and 0.7 milligrams of lead per 10 cubic meters of air.

Spray painting of finished products, with attending solvent fumes, is encountered in many plants. Not only the solvents used, but also pigments containing lead, present potential hazards. It is common practice to spray paint products in booths too small to accommodate them, resulting in dispersion of fumes and spray outside the effective range of the booth.

In any health study of a steel mill, maintenance shops should not be overlooked. It is common practice to conduct varied types of operations, often under a temporary set up. This temporary set up may last from one day to 10 years, and usually without any consideration of the exposures involved. Such operations, as metal laying using lead, cleaning of motors with carbon tetrachloride, temporary pickling and babbiting operations, and those operations involving the use of cyanide are commonly found in these maintenance shops.

The Effect of Driving Fatigue

—*On the Critical Fusion Frequency of the Eye*—

R. H. LEE *and* E. C. HAMMOND

SNELL,[3] while investigating the problem of visual fatigue caused by viewing motion pictures, found that the critical frequency of flicker was depressed following exposure of the eye to a flickering light. He reported correlations between time of exposure to a slowly flickering light and the change in critical frequency at several brightness levels. Snell also reported changes in critical frequency attributable to other types of visual tasks, such as reading, drawing, etc.

These findings were checked in a set of preliminary tests on laboratory personnel with the instrument used in this investigation. The critical fusion frequency of six subjects was measured at a constant brightness of test field and surround (approximate value of log $I = 2.3$; I is in photons). Immediately after each measurement was complete, and without permitting the subject to look away from the instrument, the eye of the subject was fatigued for several five-minute intervals by exposure to the same test field flickering at 18 cycles per second, or well below the critical fusion frequency of the lowest subject. The critical frequency was measured at the end of each five-minute period and the fatigue stimulus again applied immediately afterward. The results of this test are shown in Table 1. Subject No. 2 was suffering from a severe cold which probably accounts for the lack of recovery after a rest period.

The critical frequency of flicker is affected by a number of external factors which must be accurately controlled in any experiment. Hecht and Smith[2] have investigated the relationship between critical frequency of flicker, retinal brightness,* area of flickering field, and area of the surrounding steady field. Hecht and Shlaer[1] have also studied the effect of color. If critical frequency is plotted against the logarithm of the brightness, a double curve is formed, the lower portion of which is ascribed to the rods, the upper to the cones of the eye. Fig. 1 gives an example of the

*Retinal brightness is proportional to the external brightness multiplied by the area of the pupil of the eye.

above-mentioned relationships. The curves with circled points are plotted from Table 2 of Hecht and Smith's article and are for test fields of 6° and 19° respectively. The data are for the right eye of a single subject, E. L. S. The curve marked off in squares is similarly derived for the right eye of the subject, R. H. L., on the instrument used in this study. The test field was 12° in this case, while the brightness values were known in arbitrary units only. Making the hypothesis that the values for 12° field should fall somewhere between the values for the 6° and 19° fields, the latter curve was plotted on the same critical frequency scale as those from Hecht and Smith's data and so placed. This is not presented as a highly accurate procedure, but only to aid the reader in making a comparison between the data presented in this paper with that found elsewhere in the literature.

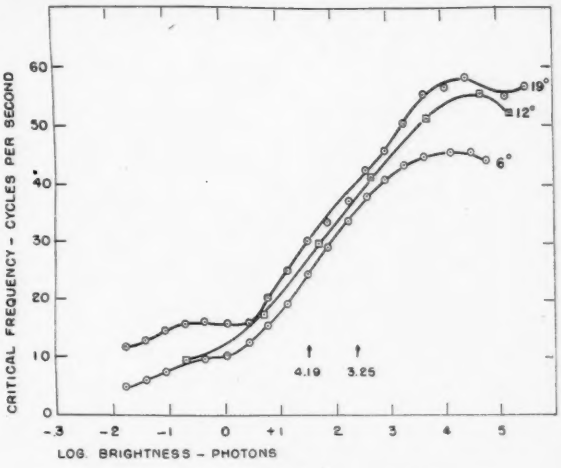

Fig. 1.
The relation between critical frequency and the logarithm of the brightness for several sizes of test fields

Subjects

THE experiments described in this paper were performed as a part of an extensive study on fatigue in relation to hours of driving of interstate truck drivers.[4] Field laboratories were set up in three cities, Baltimore, Nashville, and Chicago, where truck drivers were available for examination. The drivers reported to the laboratory and were tested immediately after a period of driving or after a rest period before starting the day's work.

A history was taken of each man, including such factors as hours of driving and hours of sleep during the previous 24 hours, years experience as a truck driver, usual hours of work, whether driving was usually done at night or in the daytime, age, and race. Each man was also given a medical examination, including a Kahn test. All but a few of the men were white. Their ages ranged from 20 to over 60, but the great majority were between 20 and 40 years old (average age 32). The age distribution was about the same in the three cities. The medical examinations found that the men were in good health, with a few exceptions.

Apparatus

THE apparatus used in this investigation has been described in detail elsewhere[4] and consisted of a modified Hecht and Shlaer[1] design for the optical system and a speed control designed and built in this laboratory.

The flickering circular test field was 12° in diameter and surrounded by an approximately circular nonflickering field of the same brightness. This field was viewed through an optical system, the exit pupil of which was smaller than the entrance pupil of the eye. The brightness of the test field and surround were controlled by neutral glass filters and wedge. Central fixation was maintained by means of a small luminous fixation point. The flicker was produced by a sector disk interrupting the beam, producing the test field at a point where an image of the source, a small luminous tungsten ball, was in focus, thus producing a sharp cut-off.

Procedure

THE following procedure was used throughout the investigation. The subject was first tested for eye dominance by the Miles method and the dominant eye only used. He was then instructed in the adjustment of the chin rest and chair. Care was taken to see that the eye was placed at the proper distance from the eyepiece of the instrument. The wedge, with neutral filter, was set to an optical density of 4.19, resulting in a value of illumination which will hereafter be designated "low brightness." The speed was adjusted to be well above the critical frequency for this brightness. The subject was then instructed to look through the eyepiece of the instrument directly at the fixation point placed in the center of the test field.

The speed of the sector disk was then lowered by the operator well below the critical fusion frequency for a moment, then increased again to the former speed to demonstrate to the subject the difference between the observable flicker below and the apparently steady light above the critical frequency. The subject was asked to tell what he saw during this demonstration to give the operator an estimation of his threshold value.

A test was now made in the following manner. The speed was lowered until flicker was reported. Then the speed was raised until the subject could observe no flicker, at which point the dials were read. A second measurement was made in the same manner before the subject was permitted to look away from the instrument. The subject was then instructed to sit back and close his eyes.

The wedge with neutral filter was now changed to an optical density of 3.25, resulting in a value which will hereafter be designated "high brightness."* ("High brightness" was therefore 8.71 times as bright as "low brightness," or a difference between the two of 0.94 log units.) The subject was then instructed to look into the eyepiece with the same eye as before and a second pair of measurements was made using precisely the same procedure as described above.

This entire procedure took approximately 12 minutes and care was taken to run each subject on the same time schedule.

*Approximate value of log I for high brightness is 2.3 where I is in photons.

TABLE 1.

THE EFFECT OF FLICKER AS THE FATIGUE STIMULUS ON THE CRITICAL FUSION FREQUENCY OF THE EYE

	Critical Frequency (cycles per second)					
	Before Application of Fatigue Stimulus	At end of 1st period	At end of 2nd period	At end of 3rd period	After Rest Period	
Subject					Period	C.F.
1	36.0	33.0	31.0	31.5	1 hour	35.9
2	41.9	36.6	32.8	...	1 hour	33.4
3	33.7	30.8	27.6	...	1 hour	33.9
4	36.2	33.5	33.4	30.5	20 min.	36.4
5	37.2	34.3	32.8	...	10 min.	35.0
6	59.6	40.8	...	...	5 min.	60.5

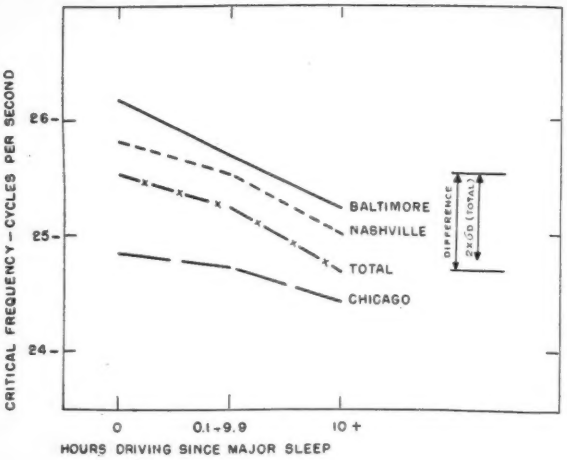

Fig. 2.
Mean critical frequency at low brightness, classified by hours of driving since major sleep, and by cities

The illumination in the room containing the flicker apparatus was at all times less than five-foot candles. The lights were always extinguished about four minutes before the test began. The subject viewed the low-brightness test field, no flicker being visible, for approximately one minute before measurements were made. Two minutes in darkness occurred between this part of the test and the high-brightness measurements. The high-brightness test field was viewed for one minute, as in the first part of the test. This short adaptation period, which was made necessary by the limited time allotted to the test, insured uniformity with regard to the state of adaptation of the subject's eye to the brightness of the respective test fields. While it is fully realized that adaptation was probably not complete in every case, each subject was treated in the same manner, so that mean values for groups of subjects should be comparable.

Results

CRITICAL frequency measurements were made on 528 subjects, some of whom were examined more than once. Only the results of the first examination on each subject are included in the following tables. Not all these subjects appear in every table, since in some instances the driving histories were unclassifiable. Two criteria only were used in discarding any data: an incompleted examination (flicker), and lack of a classifiable driving history.

The critical frequency given for any subject is the mean of two individual readings. The unit of measurement is cycles per second. Measurements were made at two brightnesses, as previously described. Whenever a mean is given at one brightness, the corresponding mean at the other brightness is for the same group of subjects.

Table 2 gives the correlation between critical frequencies at low and at high brightness for all subjects examined.

In analyzing the flicker data for differences between groups according to industrial history, the subjects were first classified by city and by hours of driving since their last major sleep (six hours or more). The subjects were divided into three groups by hours of driving, namely, those who have not driven since sleeping, those who have driven from 0.1 to 9.9 hours, and those who have driven 10 hours and over. The results are given in Tables 3 and 4. The first column indicates

TABLE 3.
CRITICAL FREQUENCY LOW BRIGHTNESS

Hours driving since major sleep	No.	Mean	S. D. of Mean	S. D.	S. D. of S. D.	C. of V.	Critical ratio
Baltimore							
0	37	26.19	0.47	2.88	0.34	11.01	...
0.1-9.9	56	25.68	.39	2.95	.28	11.49	0.84
10+	9	25.22	(1)	(1)	(1)	(1)	
0-10+	...	....	...	...	...	....	(1)
Nashville							
0	54	25.82	0.43	3.17	0.31	12.30	0.45
0.1-9.9	46	25.52	.52	3.49	.36	13.64	.75
10+	36	25.00	.46	2.79	.33	11.16	...
0-10+	...	....	...	...	...	....	1.34
Chicago							
0	57	24.84	0.30	2.22	0.21	8.92	...
0.1-9.9	70	24.72	.23	1.90	.16	7.69	.79
10+	92	24.42	.29	2.72	.20	11.14	...
0-10+	...	....	...	...	...	....	1.00
Total							
0	148	25.53	0.23	2.82	0.16	11.05	...
0.1-9.9	172	25.24	.21	2.79	.15	11.05	0.94
10+	137	24.68	.23	2.72	.16	11.03	1.80
0-10+	...	....	...	...	...	....	2.58

(1) Numbers too small to be reliable.

TABLE 2.
CORRELATION BETWEEN CRITICAL FREQUENCY AT HIGH AND AT LOW BRIGHTNESS FOR ALL SUBJECTS

Critical frequency (cycles per second) at high brightness	Critical frequency (cycles per second) at low brightness												Total
	14-15	16-17	18-19	20-21	22-23	24-25	26-27	28-29	30-31	32-33	34-35	36-37	
22-23	2	..	..	..	..	..	..	..	..	..	..	..	2
24-25	1	..	1	..	..	..	..	..	..	..	..	..	1
26-27	..	..	1	1	2	..	..	..	..	..	..	..	4
28-29	..	..	1	6	7	1	..	..	..	..	..	..	15
30-31	..	..	3	12	27	11	2	..	..	..	..	..	55
32-33	..	..	..	8	26	31	12	2	..	..	..	..	79
34-35	..	..	..	4	23	63	31	6	..	..	..	..	127
36-37	..	..	..	2	9	37	53	11	2	..	..	..	114
38-39	..	..	..	1	2	8	24	20	8	..	..	..	63
40-41	..	..	..	..	..	6	12	12	7	2	..	..	39
42-43	..	..	..	..	..	..	5	3	6	2	..	..	16
44-45	..	..	..	..	..	..	..	1	1	..	1	1	4
46-47	..	..	..	..	..	..	1	2	..	1	..	..	4
48-49	..	..	..	..	..	..	2	..	..	..	..	..	2
50-51	..	..	..	..	..	..	..	..	..	..	..	..	0
52-53	..	..	..	..	..	1	..	..	..	..	..	..	1
60-61	..	..	..	..	..	..	..	..	..	..	1	..	1
Total	3	0	6	34	96	158	142	57	24	5	2	1	528

	Low Brightness	High Brightness
Mean	25.13	35.37
Standard deviation	2.84	3.98
Standard deviation of the mean	.12	.17

TABLE 4.

CRITICAL FREQUENCY HIGH BRIGHTNESS

Hours driving since major sleep	No.	Mean	S. D. of mean	S. D.	S. D. of S. D.	C. of V.	Critical ratio
Baltimore							
0	37	37.11	0.65	3.96	0.46	10.68	...
0.1-9.9	56	35.77	.56	4.20	.40	11.74	1.56
10+	9	35.33	(1)	(1)	(1)	(1)	(1)
0-10+	...	....	...	...	...	....	(1)
Nashville							
0	54	35.91	0.55	4.05	0.39	11.28	...
0.1-9.9	46	35.26	.62	4.21	.44	11.95	0.78
10+	36	35.39	.56	3.35	.40	9.46	.15
0-10+	...	....	...	...	...	....	.67
Chicago							
0	57	35.53	0.45	3.42	0.32	9.62	...
0.1-9.9	70	34.44	.33	2.75	.23	7.98	1.68
10+	92	34.53	.43	4.12	.31	11.93	.14
0-10+	...	....	...	...	...	....	1.61
Total							
0	148	36.07	0.33	3.97	0.23	11.00	...
0.1-9.9	172	35.09	.29	3.74	.20	10.63	2.23
10+	137	34.81	.34	3.93	.20	11.29	.64
0-10+	...	....	...	...	...	....	2.68

(1) Numbers too small to be reliable.

the number of hours of driving, the second column the number of subjects in the group, and the third gives the means. The standard deviation of the mean, standard deviation, standard deviation of the standard deviation, coefficient of variability and critical ratio are given in columns four, five, six, seven and eight, respectively. The last row for each city and for the section labeled "Total" gives the critical ratio between the zero hours driving group and the 10-and-over-hours driving group.

The total was calculated by regrouping the subjects without reference to the city breakdown.

As is shown in Table 3 and Fig. 2 for low brightness, there is a consistent decline in the mean critical frequency with increasing hours of driving in all three cities. For high brightness (Table 4 and Fig. 3), the men who have driven have a lower mean critical frequency than those who have not driven, but there is little difference between the mean critical frequencies for the 0.1-9.9 hours-of-driving group and the 10+ hours-of-driving group. The differences between mean critical frequencies for different groups within any one city were not statistically significant.

When the data for all three cities are combined, the difference between the zero-hour-driving group and the 10+ hour-driving group is significant with a critical ratio of 2.58 and 2.68, respectively, for low and high brightness. The reliability of this difference should be considered with caution, however, since the difference between cities is of the same order of magnitude, e.g., the difference between means for the zero hour group at low brightness for Chicago and Baltimore gives a

TABLE 5.

CRITICAL FREQUENCY VERSUS AGE—BALTIMORE AND NASHVILLE

Age in years	No.	Mean	S. D. of Mean	S. D.	S. D. of S. D.	C. of V.
Critical Frequency Low B						
Under 30	122	25.70	0.27	3.00	0.19	11.67
30-39.9	119	25.66	.28	3.07	.20	11.96
40+	34	25.32	.48	2.78	.34	10.98
Critical Frequency High B						
Under 30	122	35.72	0.37	4.04	0.26	11.31
30-39.9	119	35.89	.34	3.72	.24	10.36
40+	34	35.62	.85	4.96	.60	13.92

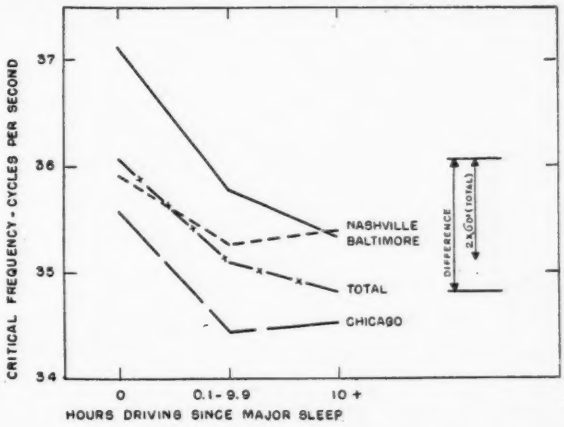

Fig. 3.
Mean critical frequency at high brightness, classified by hours of driving since major sleep, and by cities

critical ratio of 2.45, and for high brightness a critical ratio of 2.

Table 5, showing critical frequency versus age, was prepared by combining the data from Baltimore and Nashville only, since the critical frequencies are at a different level in Chicago. No marked difference between the age groups is to be observed. It will be recalled, however, that very few of the drivers examined were over 45 years old.

Conclusions

MEASUREMENTS of critical frequency made on 528 subjects in Baltimore, Nashville, and Chicago show differences in the mean between groups classified by hours of driving since major sleep. In general, these differences show a slight but consistent tendency toward lower critical frequency with increasing hours of driving.

Within the age limits of these drivers no age trends were discernible.

Relative large differences were found in the critical fusion frequency of men examined in the three cities. Differences between men tested in the three cities were also found by other investigators[4] on this study in connection with driving tests, psychomotor reactions, white blood cell counts and other tests of quite diversified nature.

[The authors are greatly indebted to the executive and medical personnel of the Division of Industrial Hygiene who arranged for space and subjects and supervised the taking of the histories and the administration of physical examinations.]

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MEDICINE from the Bench: "There may be some question as to whether silicosis, like hay fever, may only occur to a disabling extent in comparatively few persons. Possibly the employer made liable for silicosis is somewhat in the situation that the restaurant keeper would be if he were liable for injury to a person made ill eating onions. Silicosis may be akin to allergy."—Lackawanna County's Judge Leach, quoted in *Carbondale, Pennsylvania Leader*, June 15, 1942.

Industrial Hygiene Control

—On Tunnel Construction in Hydro-Electric Projects in Western North Carolina—

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IN THE early summer of 1940 there were begun, in western North Carolina, hydro-electric projects to harness the waters of the Tuckaseigee and Nantahala rivers. These developments were conceived to meet increased power needs for the production of aluminum in a plant that was to be enlarged. The country through which the streams flow is mountainous and for obvious reasons the construction of power tunnels was planned.

As certain serious occupational disease hazards may arise in such work, the role of the Division of Industrial Hygiene in this important undertaking was delineated.

Scope of Industrial Hygiene Supervision

THE pre-employment examination of workers selected for jobs that will expose them to the hazards of silicosis is mandatory under North Carolina law[1] and, inasmuch as the Division of Industrial Hygiene has been given the responsibility for them,[2] it became necessary to consider first this phase of industrial hygiene control of the projects. Accordingly within a few weeks of the beginning of operations the mobile x-ray laboratory[3] of the Division had been dispatched to the scene of operations and the examination[4] of workers was actively under way.

An appraisal of the hazards to health attending the construction of the tunnels was begun some weeks later, as was also, the quarrying and the crushing of stone.

The burden of this presentation, however, is to submit the results of the study of the occupational environment in the tunnels, to the exclusion of all surface work. The physical fitness of the men for such employment probably will be discussed in a subsequent paper dealing exclusively with the medical aspects of the work. There were examined on these projects 1711 persons.

Description of Projects

THE two hydro-electric projects are identical in that both involve the construction of earth dams. At each place the impounded waters will be carried down grade through a series of tunnels and penstocks to power plants.

On the Tuckaseigee river project there have been constructed three tunnels between the dam and the site of the power plant. Two of the power tunnels are 12 feet in diameter and together are 8221 feet in length; the third is 9 feet in diameter and 4803 feet in length. Thus, there are almost three miles of power tunnels at this job. On the Nantahala river there are two power tunnels under construction; both are approximately 13 feet in diameter and are to be about 4½ miles and 1½ miles in length, respectively. On both jobs a short drainage tunnel and a short diversion tunnel either have been completed or are under construction; these, of course, are in addition to the power tunnels. The underground operations at both projects have involved some vertical work; it consisted of shaft sinking from the surface at Tuckaseigee and both shaft sinking and stoping at Nantahala.

The water head at Tuckaseigee is to be 1215 feet, developed from a lake that will be approximatey four square miles in area; two 10-inch diameter nozzles operating one turbine will generate 30,000 K. W.* At Nantahala the water head is to be approximately 1000 feet developed from a lake approximately three square miles in area; here one turbine of the reaction type will generate 65,000 K.W.

High tension lines will deliver the power to the aluminum recovery plant.

Tunnel Construction

THE tunnel driving on both jobs has been essentially the same, although some of the machines employed have varied as to the type of power utilized and the mode of operation. At the time of the investigation the Conway electric mucker was used in the large tunnels and the Finley air mucker in the smaller one. In all headings drilling was done by "Jumbos" that mount from five to six drifter drills each. About two hours were required for drilling and loading holes. In the 12-foot to 14-foot diameter tunnels from 38 to 40 holes were drilled at a time and in the 9-foot tunnels, 34 holes. The depth of the holes varied in the same heading; for example, in the large Nantahala tunnel the holes nearest the periphery were drilled 11 feet deep, using 12 foot steel, whereas, in the center the depth was only 9 feet. All holes were approximately 1¼ inches in diameter. After blasting, a mechanical mucker and an accompanying crew of electricians and pipe fitters moved in. The water, air, and electric lines were extended as the mucking machine cleaned up the rock that had been blasted down. Frequently, the tunnel tracks were covered with rock for a distance of 250 feet from the tunnel face. After about two to four hours of this the Jumbo replaced the mucker and the cycle began all over again. Timbering was unnecessary except at and near the portals. In some tunnels the driving was advanced 40 feet every 24 hours, although the average was less.

Health Safeguards

THERE were health safeguards in use. All drills were equipped with the New York State type drill heads through which flow approximately two gallons of water per minute. Prior to the beginning of mucking, the rock blasted down was wet to reduce generation of dust. In addition there was installed in each tunnel a ventilation duct. At one of the tunnels the ventilation was provided by blower; in the others, however, the ventilation was accomplished by both exhaust and forced drafts produced by reversible compressors.

Despite the use of safeguards serious occupational disease hazards existed in the tunnels.

Atmospheric Dust Concentrations

SAMPLES of atmospheric dust were collected with the large impinger[5] in all of the power tunnels. Light field technique was employed for particle counts. The results of this work are presented in Tables I and II.

The amount of dust in the air at the Jumbos, with all drills in operation was not excessive. Concentrations ranged from 7.7 to 18.5 million particles per cubic foot of air (samples 1, 2, 10 and 11). Strangely enough this identical range of dust concentrations was found for similar tunnel work by an industrial hygiene engineer in a western state.[6] The results, then, are considered representative of the dust exposures for such work. The concentration of atmospheric dust 100

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*There will be one shaft with a generator in the center and two separate water wheels, one on each end of the shaft.

TABLE I
RESULTS OF PARTICLE COUNTS ON SAMPLES OF ATMOSPHERIC DUST COLLECTED IN TUNNELS AT THE TUCKASEIGEE PROJECT

Date 1940	Sample No.	MPD/CFA*	Description
9/24	1	12.3	Exposure of men working alongside Jumbo at tunnel face. (Portal 3)
	2	18.5	Exposure of men on top of Jumbo—sample collected simultaneously with No. 1.
10/28	3	14.3	General atmosphere between Finley air mucker and tunnel face; distance approximately 10 feet. (Portal 6)
10/29	4	49.9	General atmosphere at tunnel face. Conway electric mucker in operation about 15 minutes. Muck wet. (Portal 3)
"	5	342.0	Sample obtained immediately after mucker had uncovered pocket of dry material. (Portal 3)
"	6	20.5	General atmosphere in tunnel approximately 100 feet from heading, 1½ hours after blasting. Mucker running. (Portal 2)
"	7	10.8	General atmosphere in tunnel approximately 100 feet from heading, 1 hour and 40 minutes after blasting. (Portal 3)
11/1	8	42.8	General atmosphere on muck pile after blasting. Muck being wet. Mucker operating. (Portal 2)
"	9	30.2	General atmosphere approximately 50 feet behind mucking machine immediately following collection of sample 8.

*Million particles of dust per cubic foot of air.

feet from a Jumbo in operation was only 6.1 million particles (sample 12) whereas, 2200 feet down the tunnel it was only 1.2 million particles. The cleaning up and removal of the rock blasted down was far dustier, despite the liberal wetting of the muck prior to its removal. The heavy charges of explosives used reduced much of the rock to extremely fine fragments. Particle counts on three of five samples collected at mucking machines while they were in operation revealed concentrations ranging from 12.8 to 342.0 million particles (samples 4, 5, and 8), the latter occasioned by the uncovering of a dry pocket of rock. The sample yielding the high particle count was collected over a 10-minute interval beginning immediately after it was observed that the tunnel atmosphere was becoming dustier; it was collected near the working face to measure the increase in atmospheric dust concentration incident to encountering unwetted material. The other samples revealed much lower concentrations (samples 3 and 14). From 50 to 100 feet from the mucker the dust concentrations ranged from 10.8 to 30.2 million particles.

The rock formation at the Tuckaseigee project is a granitic gneiss and at the Nantahala job it is more complex, being identified as Great Smoky Mountain conglomerate. The petrographic analysis of several samples of aggregate and dust from both jobs revealed the gneiss to contain an average of 50% quartz, or free silica, and the conglomerate, 20%. The concentrations of atmospheric dust in the Nantahala tunnels are not excessive and as the quartz content of the mineral is relatively low the siliceous dust exposures are considered unobjectionable. At the Tuckaseigee project, however, the dust exposures are high and the mineral involved is half quartz. The existence of a definite silicosis hazard, therefore, is indicated for this job.

TABLE II
RESULTS OF PARTICLE COUNTS ON SAMPLES OF ATMOSPHERIC DUST COLLECTED IN TUNNELS AT THE NANTAHALA PROJECT

Date 1940	Sample No.	MPF/CFA*	Description
9/26	10	7.7	Exposure of men working on top of Jumbo at tunnel face. (Portal 1)
"	11	10.5	Exposure of men working under Jumbo. Sample collected simultaneously with No. 10.
"	12	6.1	General atmosphere in tunnel 100 feet from Jumbo in operation. (Portal 1)
"	13	1.2	General atmosphere in tunnel approximately 2200 feet from Jumbo in operation and about 4500 feet from Portal. (Portal 1)
11/5	14	20.8	General atmosphere around the mucker. (Portal 2)

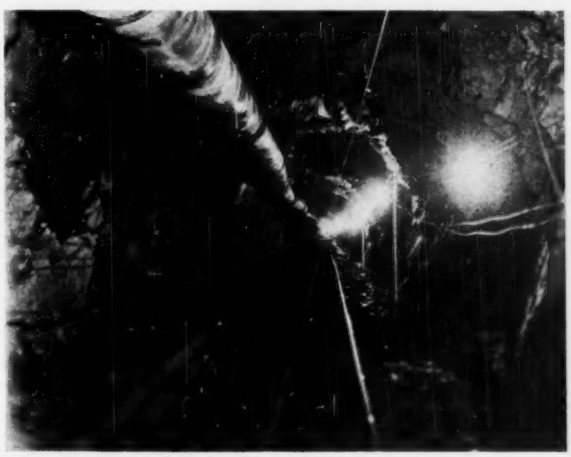
*Million particles of dust per cubic foot of air.

North Carolina's mobile x-ray laboratory on location at the Tuckaseigee dam site

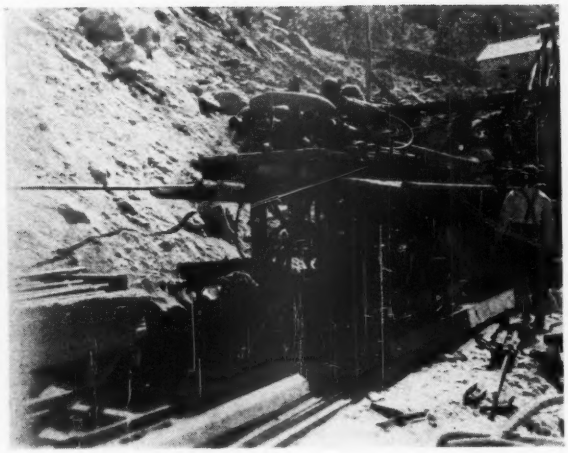
Carbon Monoxide

THE other occupational disease hazard evaluated was carbon monoxide. As the gas originates in the discharge of explosives it may be of interest to preface the discussion by outlining the loading practices. The dynamite used was 40% gelatin, except for a small amount of 60% gelatin employed for "springing" liner shots. In the 12-foot Tuckaseigee power tunnels, the 40 holes that were usually drilled were each loaded with 8⅓ lbs. of dynamite for a total of 334 lbs. to a round; in the 9-foot tunnel the usual 34 holes were loaded with 4½ lbs. each for a total of 155 lbs. At Nantahala, the 13- to 14-foot diameter power tunnel was advanced by drilling 38 holes and filling each with 12 lbs. of dynamite for a total of 450 lbs. to the round. The amount of the charge was, of course, determined in part by the depth of the drill holes. At Tuckaseigee the 9-foot tunnel was advanced 5 feet by each blast and the 12-foot tunnel, 7 feet. At Nantahala the 13-foot tunnel was increased in length by approximately 10 feet at each blast.

According to the U. S. Bureau of Mines[7] "all permissible explosives when detonated emit some poisonous gases and a much larger volume of non-poisonous gases. In order that the poisonous gases may not under normal conditions become a menace to the lives or



Tunnel interior at Nantahala from point 200 feet from portal, at 9-16-40. Heading 6700 feet from surface



The business end of a Jumbo which drills six holes simultaneously

health of miners, no explosive is now or can become permissible if it evolves upon detonation more than 158 liters (5½ cu. ft.) of poisonous gases per 1½-pound charge, as determined by tests in the Bichel pressure gage.

"The classication on the basis of the volume of poisonous gases produced by 680 grams (1½ pounds) of explosive is as follows: Class A, not more than 53 liters; class B, between 53 and 106 liters; and class C, between 106 and 158 liters."

In a test with an explosive that produced the maximum allowable quantity of poisonous gases the results indicated "that in a narrow entry, without artificial ventilation, 0.18% of carbon monoxide (the only poisonous gas present) was produced, as shown by analysis of an air sample taken two minutes after the shot." Sayers and Yant[8] report the presence of 1.2% carbon monoxide in mine air seven minutes after blasting with 100 sticks of gelatine dynamite.

The dynamite used on the tunnel projects was obtained from two manufacturers each of whom makes several brands that are rated as class A. The particular *brands* used, however, were not known at the time this paper was prepared.

The MSA continuous carbon monoxide indicator was employed for most of the testing. This instrument was supplemented by U. S. Bureau of Mines evacuated bottles in which samples of mine atmospheres were collected. These samples were later analyzed by the Bureau. The results are presented in Table III.

An electrically operated mucker, Tuckaseigee job

These results reveal that all power tunnel atmospheres in working areas frequently contain concentrations of the gas in excess of 0.01% carbon monoxide, the generally accepted[9] maximum permissible limit. The tests with the continuous recorder were most often begun in a heading with the arrival of the first men following blasting. This was usually 30 minutes after shooting during which interval the tunnel was ventilated: by exhaust for the first five or 10 minutes and then by forced draft. Only in the short diversion tunnel (Result No. 11) were only negligible concentrations found.

In the Portal No. 2 tunnel at the Tuckaseigee job the atmospheric concentrations of carbon monoxide, as determined by the continuous recorder, were negligible, with one exception. Up near the tunnel face and in a pocket cut into the muck pile by the power shovel the concentration of the gas exceeded 0.1%,—10 times the permissible limit, and more than the indicator would record. The report of a grab sample collected in a U. S. Bureau of Mines bottle when these tests were in progress and subsequently analyzed by this agency revealed a concentration four times that of the threshold limit. In Portal No. 2 of the Nantahala

TABLE III
CARBON MONOXIDE CONCENTRATIONS IN THE POWER TUNNELS OF TWO HYDRO-ELECTRIC DEVELOPMENTS IN WESTERN NORTH CAROLINA

Result No.	Date	Tunnel	Sampling Place	CO in Parts per 10,000	Kind of Sample
		TUCKASEIGEE PROJECT			
1	11/1	Portal No. 2	Approximately 350 ft. from Portal and about 10 ft. from face, ½ hour after blasting	0.70-0.45	Continuous at ½ min. interval for 3 min.
2		"	Ditto	4.00	Grab sample
3		"	Nearer face in muck pile pocket	More than 10.00	Continuous for 1 minute
4		"	Approximately 290 ft. from Portal and about 60 ft. from face 1 hr. after blasting	0.34-0.05	Continuous at 1 min. interval for 5 minutes
5	10/30	Portal No. 3	Approximately 1200 ft. from Portal and 10 ft. from face. 25 minutes after blasting	3.50	Continuous at 1 min. interval for 5 minutes
6		"	Ditto—1 hour after blasting	Less than 1.00	Grab sample
7	10/31	Portal No. 6	Approximately 1000 ft. from Portal and about 50 ft. from face, alongside mucker part of time, 25 minutes after blasting	2.00-2.80	Continuous at ½ to 5 min. intervals for 49 minutes
8			Ditto	2.80-1.90	Continuous at ½ to 5 min. intervals for 46 minutes
9	11/1	Portal No. 6	Approximately 1000 ft. from Portal and about 10 ft. from face 20 minutes after blasting	Less than 1.00	Grab sample
10		"	Ditto—100 ft. from face immediately after above	Less than 1.00	Grab sample
		NANTAHALA PROJECT			
11	11/4	Diversion Tunnel	Approximately 300 ft. from Portal and about 15 ft. from face 30 minutes after blasting	0.40-0.08	Continuous at 3 to 5 min. intervals for 30 minutes
12		"	Ditto—30 minutes after blasting	Less than 1.00	Grab sample
13	11/5	Portal No. 2	Approximately 300 ft. from Portal and about 20 ft. from face 35 minutes after blasting	5.50-2.00	Continuous at 1 to 2 min. intervals for 9 minutes
14			Ditto—compressed air directed into heading after above readings recorded —sampling continued	1.80-1.10	Continuous at 2 min. interval for 12 minutes
15	11/6	Portal No. 1	Approximately 6200 ft. from Portal and about 20 ft. from face 55 minutes after blasting	2.50-2.70	Continuous at 2 to 3 min. intervals for 38 minutes
16		"	Just prior to blasting	Less than 1.00	Grab sample
17	"	"	Ditto—55 minutes after blasting	3.00 1.00	Grab sample
18	"	"	Ditto—1 hour and 40 minutes after blasting	Less than 1.00	Grab sample

project the dispersal of the gas was hastened by directing compressed air into the heading. (Results Nos. 13 and 14.) Despite this use of compressed air in the tunnel, which at the time had been driven only 300 feet, the concentration of the gas 12 minutes later was still above the threshold limit. In the other three power tunnels, in which tests were made the concentrations of the gas exceeded the threshold limit. On the Tuckaseigee job the conditions in the Portal No. 6 tunnel were especially objectionable. This is the smaller of the three tunnels, being 9 feet in diameter. Here, an excessive concentration of the gas persisted during the hour and 35 minutes that the recorder was operated following the return of the men to the heading after blasting. On the Nantahala project, the conditions in the large No. 1 Portal tunnel were unsatisfactory at the face. The concentration of carbon monoxide was almost three times the threshold limit 38 minutes after the men returned to work; a grab sample collected 55 minutes after the return of the men to the heading revealed litle change in concentration. At this time the tunnel had been advanced only 6200 feet from the portal, and as it is deepened the ventilation problem will become progressively greater.

The North Carolina experiences with carbon monoxide have been corroborated by the industrial hygienist in a western state who has been referred to previously. He states[6] "that there was a presence of 0.02 to 0.03% remaining for 35 minutes after blasting on top of the muck pile where four to five men are wetting down muck during this interval of time."

The industrial hygiene engineers who entered the tunnels, all developed throbbing headaches within a short time; and there were four of these men, including a visitor to the state and a man on special assignment from the U. S. Public Health Service to assist in the work. The state engineers were not peculiarly susceptible, therefore. Some of the tunnel workers complained of headaches and one of the state physicians reported that frequently in examining men coming off duty he would find their faces flushed, pulse rapid, and blood pressure elevated.

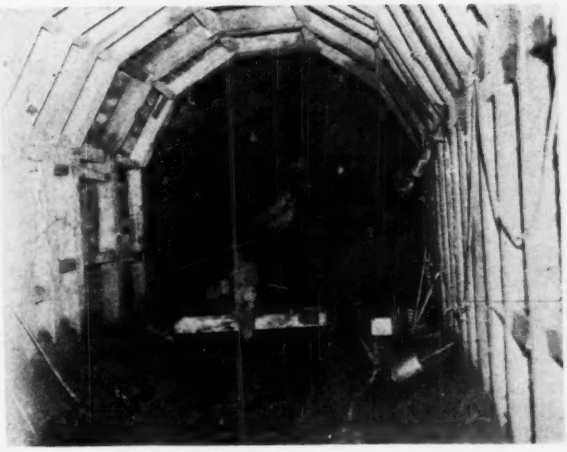
In this connection our western correspondent[6] has written that "30 blood analyses have been made on the men working in the heading and they average between 25% to 35% saturation of carbon monoxide in the blood."

Drinker[10] states that at the threshold limit of .01% or 100 ppm, the maximum hemoglobin saturation is only 17% due to the establishment of a state of equilibrium at this atmospheric concentration. The U. S. Public Health Service[9] is authority for the statement that the blood saturation of from 10% to 20% of carbon monoxide hemoglobin will produce "tightness across forehead, possibly slight headache, dilation of cutaneous blood vessels," and that a blood saturation of from 20% to 30% produces "headache, throbbing in temples," which are the symptoms most frequently experienced by the state engineers.

The carbon monoxide concentrations in the tunnels were frequently sufficient to result in 20% to 30% blood saturations.[9]

The analysis of air samples collected in a water supply tunnel under construction in a western state is of interest. Here,[11] "samples of gases taken on a muck pile 30 minutes after firing 73.7 lbs. of 40% Ex. L. F. Gelatin in a 45° raise . . . revealed . . . 99 p.p.m. of oxides of nitrogen and .24% carbon monoxide."

It appears, then, that the North Carolina experiences in tunnel construction are in agreement with the results of public health workers on similar projects elsewhere.



A tunnel is timbered until rock is encountered, in this instance approximately 100 feet

Ventilation Studies

IN ALL tunnels the ventilation ducts were found to end too far from the heading. In every tunnel they were at least 175 feet short of the working face and in two of them fully 300 feet. In some tunnels the volume of air delivered would have been adequate if delivered nearer the working face; the approximate air volumes varied from 1500 cfm to 10,000 cfm. It was evident, however, that so long as the ventilation ducts terminate 200 feet or more away, no reasonable amount of air would adequately ventilate the working areas.

Conclusions and Recommendations

THE HEALTH protection facilities, as operated at the time of the investigation, were not adequate to prevent the development of occupational health problems. A serious siliceous dust hazard accompanied both drilling and mucking operations on the Tuckaseigee project. Here, the dust concentrations were high and the rock formations from which the dust originated contain 50% quartz. The dust problem was less acute at the Nantahala operations as a result of lower concentrations and the involvement of a mineral that contains only 20% quartz. As water was the principal safeguard employed at both jobs it appeared that insufficient use of it was being made, especially on the Tuckaseigee project. Carbon monoxide was at times present in all tunnels in sufficient concentrations to cause distress. The ventilation of headings was inadequate due mainly to the termination of ducts 175 feet, or more, from the working face.

The major recommendations were, first, that muck piles be wet continuously during mucking operations to minimize dust generation resulting from the uncovering of dry pockets of material; and second, that the metal ventilation duct be kept within 150 feet of the working face at all times, probably through the use of a movable metal shield to protect the end during blasting, and that the duct be extended with canvas vent-tube to within 50 feet of the face following each blast.

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Discussion

WARREN A. COOK, Chicago: Mr. Trice has asked me to discuss this paper in the light of subsequent data which we obtained at these same tunnels. The results reported in his paper were secured during the fall of the year when the tunneling operations were first started. We followed up with similar determinations in January and again in April.

At both of these projects recommendations were made by the North Carolina Division of Industrial Hygiene to the contractors for the reduction of dust exposures. These were for the most part carried out prior to the collection of our samples. The results we obtained represent conditions where dust had been brought under better control in consequence of compliance with the state recommendations.

Dust concentrations at the beginning of operations in the Tuckaseigee River Project tunnels were found by Trice to be excessive on the basis of 50% quartz content of the rock through which the tunnel is being drilled. In January we found that the dust exposure during mucking operations averaged 10.4 million particles of dust per cubic foot of air (MPCF) with a maximum of 13.5 MPCF and a minimum of 8.5 MPCF. Five of the six drills for which connections were available on the Jumbo were in operation when drill dust samples were being collected. In these operations the average concentration found was 11.6 MPCF with a maximum of 16.8 MPCF and a minimum of 6.6 MPCF. It would have been preferable to have had sufficiently increased ventilation to keep these concentrations at less than an average of 10 million particles per cubic foot of air. However, the average concentrations were not significantly greater than the suggested limits and added ventilation was not installed since the tunnels were being holed through the following month.

At the Nantahala Project where the quartz content of the rock was about 20%, conditions were also found to be more satisfactory. In April, at three of the four headings, the average exposure during mucking operations was found to be 7.0 MPCF with a minimum of 4.7 MPCF and a maximum of 13.0 MPCF. During the drilling operations the average exposure was found to be 6.4 MPCF with a minimum of 3.7 MPCF and a maximum of 9.1 MPCF.

The fourth heading at the Nantahala Project had been drilled to a distance of 1800 feet from the portal at this time and the exhauster which had been installed at the beginning of the operation was still being used. Air could not be blown into the tunnel but merely drawn out through the duct. Here the average exposure during mucking operations was shown to be 32.7 MPCF and during drilling operations 15.5 MPCF. On being informed of these results the contractor immediately installed a unit which permitted exhausting air from the tunnel for the first 30 minutes after the shot and blowing air into the tunnel for the remainder of the period—the procedure followed at the other headings.

(A further series of dust determinations was made at these tunnels following the Annual Meeting at which this discussion was presented but is included here to give a more complete picture of conditions. Exposures during mucking operations showed an average of 4.5 MPCF with a maximum of 6.9 MPCF and a minimum of 2.7 MPCF. During drilling operations exposures averaged 8.8 MPCF with a maximum of 9.6 MPCF and a minimum of 7.4 MPCF. The ventilation ducts at both of the headings where operations were still being conducted were less than 100 feet from the heading and in one heading a volume of 4900 CFM and in the other 4600 CFM was being directed against the face. Contributing to the effects of the exhaust ventilation in reducing the dust concentration during mucking operations, muck piles at both of these headings were being well wet down.)

BLOWING VERSUS EXHAUSTING: There had been considerable discussion concerning the relative merits of (1) exhausting air during the entire period or (2) continuing the procedure of following a 30-minute exhaust after the blast with blowing during the remainder of the operation. Samples were taken under similar conditions during mucking and during drilling while air was being exhausted and also while air was being blown in toward the face. During the former operation, the average exposure of the muckers was found to be 7.3 MPCF when air was being blown against the face the 11.0 MPCF when air was being exhausted. During drilling, the exposure during blowing was 3.7 MPCF and during exhausting 6.5 MPCF.

COYOTE HOLE DRILLING: In April and also in August coyote holes were being drilled—an operation not in progress during the fall when Mr. Trice was making the determinations presented in his paper. This operation involves the drilling of a tunnel 3 feet in diameter into the face of the quarry at the level of the quarry floor for a distance of 30 or 40 feet and then drilling out on both sides to form a T. After this so-called coyote hole has been drilled, it is filled full of dynamite and the entire face of the quarry is then shot down.

In April the two ends of the T were being drilled, a driller and chucker operating a wet drill at one end and one man mucking with pick, shovel and wheelbarrow at the other end. Although these men drill wet, it was noted that they collar the holes dry. Even though instruction can be given to collar wet, there is little opportunity for supervision in such operations owing to their extremely confined nature. Exposures tend to be greatly variant depending upon the manner in which the work is being carried on. In April, much difficulty was being encountered in drilling the holes and, over the 15-minute period during which the sample was being collected, drilling was conducted less than half of this time. A concentration of 11.6 MPCF was found at the exposure of the driller. In August drilling was being done in the stem of the T and drilling operations were being conducted continually throughout the 12 minutes required to complete one hole. A dust concentration of 66.0 MPCF was found at the breathing zone of the drillers, most of which was due to the dust cloud set up during dry collaring.

Exposure of the mucker working in the end of the T was found to be 7.0 MPCF and that of the muckers in the stem of the T was shown to be 3.1 MPCF. While carrying on operations in the stem of this T, the driller and the chucker must conduct these two operations of drilling and mucking alternately. Their lower exposure during mucking was probably due to the fact that drilling was not being conducted at the same time as was the case where mucking was being done at the end of the T. It was calculated that the average exposure of the workers drilling the coyote hole under conditions existing in August was about 25 MPCF since they conducted all of the operations including the shooting over the entire shift. Where extensive coyote hole drilling is being carried on, samples of longer duration than those taken during these two periods are necessary in order to obtain accurate evaluation of the average dust exposures in view of the variability of the dust concentrations to which these men are subject. It would appear that every effort should be made to induce such workers to abandon dry collaring and keep the water turned on throughout the drilling operations, as is now the custom in driving ordinary rock tunnels.

In conclusion, the North Carolina Division of Industrial Hygiene is to be commended on its action in conducting a scientific study of conditions at the beginning of these rock drilling operations so that more adequate control measures could be instituted in accordance with their recommendations before the workers had experienced any appreciable exposure to excessive dust concentrations.